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New Autographic Testing Machine
FOR
Yarns and Fibres

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A NEW AUTOGRAPHIC TESTING MACHINE FOR YARNS AND FIBRES

By S. A. Shorter, D.Sc., and W. J. Hall, B.Sc., A.R.C.S.

(British Research Association for the Woollen and Worsted Industries.)

CONTENTS

1.—INTRODUCTION

The machine described in the present paper is the outcome of an effort to design an instrument for research into the elastic properties of yarns and fibres. The existing machines seem to us to possess fundamental defects—defects of principle, not merely of detailed design—which in our machine we have endeavoured to avoid. A study of the dynamical principles underlying the action of testing machines suggested the main outlines of an instrument in which these defects should be practically non-existent. Our machine in its finished form, though it contains many minor details not originally thought of, does not deviate in any fundamental particular from the original plan.

An autographic machine works by producing two motions—that of a pen and that of the paper on which the pen writes. The simplest type of diagram is produced when the two motions are at right angles and proportional to the two quantities the relation between which is being studied. In the case of a yarn-testing machine we are studying the relation between the tension and extension of the yarn, so that this type of diagram would necessitate the production of two motions proportional to these quantities. We meet here a difficulty. If the top end of the yarn is fixed to a spring and the bottom end to the stretching mechanism, we obtain two motions, that of the top yarn clamp equal to the extension (or sag) of the spring (and measuring therefore the tension), and that of the bottom yarn clamp equal to the extension of the yarn plus the extension (or sag) of the spring. It needs some special device to obtain a motion equal to the extension of the yarn, which is the relative motion of the two ends of the yarn. We are no better off if we interpose the spring between the lower yarn clamp and the stretching mechanism. In this case we get the extension of the yarn directly, but need some motion-compounding device to get the extension of the spring. Various means have been used to surmount this fundamental difficulty. The most elegant in principle and the soundest dynamically is that adopted in the Neates' extensometer. Other methods which have been used involve devices which introduce errors due to the friction and inertia of the moving parts. In our opinion the adaptations of the Barr wire-tester used by New* and Matthew† are open to criticism in this respect.

* *J. Text. Inst.*, 1922, **13**, 25. † ibid, p 45.

The fundamental idea of the new machine is the attainment of mechanical simplicity by the abandonment of all motion-compounding devices. The top end of the yarn is attached to the spring and the bottom end to the stretching mechanism. The pen is attached to the spring and partakes of its vertical motion. The paper is attached to a carriage, which by means of a simple mechanism is made to move horizontally at a rate equal to that of the vertical motion of the lower end of the yarn. If, say, the paper moves to the right the pen moves over the paper to the left and downward. The nature of the graph is easily understood. Let O (Fig. 1) represent the starting point. Let Ox and Oy be lines from O going horizontally to the left and vertically downwards respectively. Let P be any point on the graph. Let PA and PB be perpendiculars down from P to Ox and Oy respectively. The displacement relative to the paper of the pen point from O to P is compounded of a horizontal displacement to the left of magnitude OA or BP and a vertical displacement downwards of magnitude OB or AP. The latter is equal to the extension (or sag) of the spring, and therefore is proportional to the tension of the yarn. The former is equal

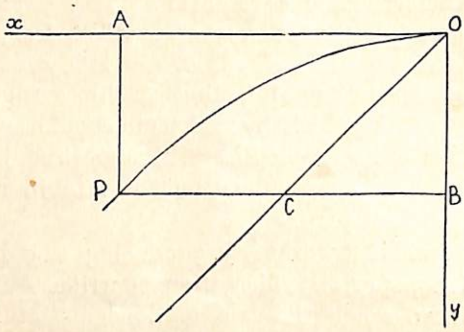

Fig. 1.

to the sum of the extension (or sag) of the spring and the extension of the yarn. If from BP we mark off BC equal to OB (or AP), then CP is equal to the extension of the yarn. The line OC is evidently at an angle of 45° with Ox and Oy.

We see that tension and extension are recorded in a fairly simple manner. The tension corresponding to any point on the curve is proportional to the distance of the point from a horizontal line through the starting point, while the extension is equal to the distance of the point (measured along the horizontal) from a line through the starting point drawn downwards to the left at an angle of 45° with the horizontal.

The diagram, though it records the facts as to the behaviour of the yarn, does not display these facts in absolutely the simplest manner possible, *i.e.*, as a stress-strain diagram referred to rectangular co-ordinates. The curve given is a stress strain diagram referred to a system of oblique co-ordinates. Of all possible systems, such a system is next in order of simplicity to rectangular co-ordinates. It has, moreover, the advantage that work done or energy dissipated is recorded as an area just as in the case of rectangular co-ordinates.

This slight lack of simplicity in the recording of the facts is an infinitesimal evil compared with the mechanical complexity required to cure it. Thus

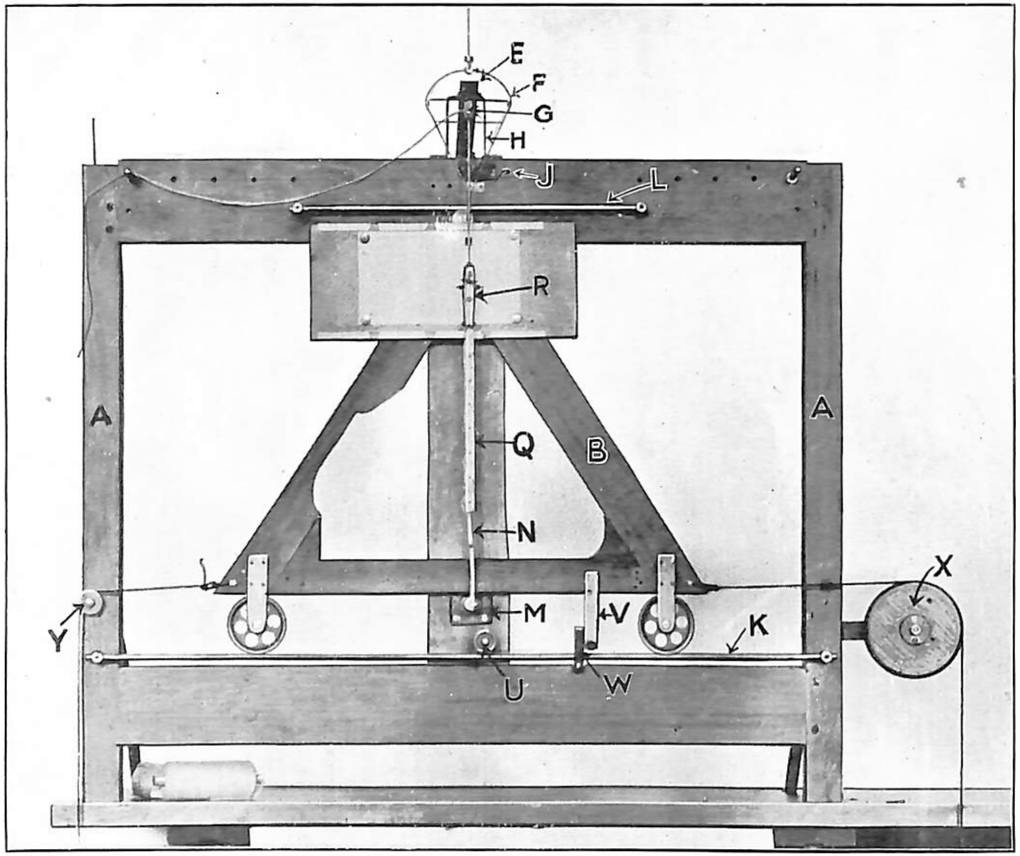

FIG. 2.

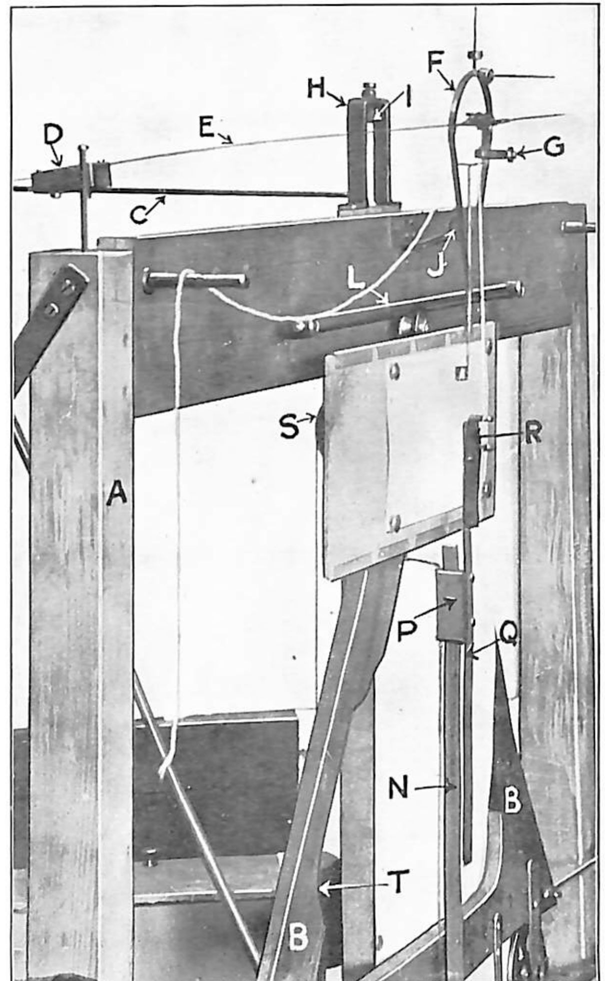

FIG. 3.

the complex arrangement of pulleys and levers used in the Barr wire tester produces simplicity in the record by sacrificing the accuracy of the record. It is true that errors due to inertia and friction may be reduced by working slowly, but such a restriction is fatal in the case of an investigation into the elastic properties of yarns and fibres. The time element is a vital factor in such an investigation, so that a machine giving accurate results when worked at a comparatively high speed is an absolute necessity.

Before proceeding to describe in detail the new machine, we will show how its main outlines were fixed by certain dynamical considerations.

2.—CERTAIN DYNAMICAL PRINCIPLES UNDERLYING THE ACTION OF TESTING MACHINES

The tension of the yarn is measured by means of some instrument attached directly or indirectly to one end of it. There are two sources of error in such an instrument: (1) inertia of the moving parts, (2) friction. When the instrument is calibrated (say, by hanging weights), the first source of error does not come into play, and the second can in general be made negligible, so that we have the relation

force indicated = force applied.

When the machine is used for testing, the corresponding relation

force indicated = tension of yarn

is generally untrue. The true relation is

difference between force indicated and tension of yarn = sum of inertia effect and friction effect.

The inertia effect is due to the tendency of the moving parts to resist change of velocity. The effect is reversible; it may hinder or help the motion, the former effect occurring when the motion is being accelerated, the latter when the motion is being retarded. The friction effect, on the other hand, is irreversible, being such as always to oppose the motion.

The inertia effect, though it is not generally recognised as such, is familiar to many users of the ordinary single-thread tester of the pendulum type. The pointer, instead of moving in a steady manner to correspond to the steady fall of the oil plunger, moves in a peculiar jerky manner, periodically coming to a momentary stoppage and then speeding up again. This is not due to any peculiarity in the elastic properties of yarns, as is thought by some workers. It is purely an inertia effect. It can be observed in a very marked manner if a strip of rubber be used in the machine instead of the yarn. The dynamical theory of the effect has been worked out by us in another communication.

This effect is the most serious obstacle to the use of the pendulum machine as part of an autographic arrangement. The fact that the pendulum machine gives an uneven scale is a minor defect which can, as will be shown in another communication, easily be overcome. The inertia effect however, cannot be overcome, and absolutely rules the machine out as the basis of an autographic machine.

We must, therefore, use some form of spring for measuring the tension of the yarn. It is quite an easy matter to obtain a spring of given strength with practically as small an inertia (*i.e.*, as rapid a period of oscillation) as we like (see Appendix). Of the two most simple types of spring—the spiral

spring and the cantilever spring—we have chosen the latter as being the better from the inertia point of view, and more rigid in directions other than the direction of sag. It is possible that in the case of short springs the scale may not be absolutely even, but this involves a sacrifice of simplicity and not of accuracy.

3.—DESCRIPTION OF THE MACHINE

The machine is shown in Fig. 2 and Fig. 3, both reproduced from photographs. Fig. 3 shows details not visible in Fig. 2. To show up certain details in Fig. 3 a sheet of white paper has been pinned to the central upright of the frame and the right-hand part of the carriage.

The machine consists of two main parts, the frame A, and the carriage B. To the frame are attached :—

C a bracket carrying an adjustable saddle D, which holds a cantilever spring E, carrying at its free end the pen carrier F and the upper yarn clamp G ;

H an iron arch carrying an adjustable rubber buffer I to prevent damage when the yarn breaks and releases the spring ;

J a lever for raising the pen from contact with the paper when a trace is not desired ;

K the rail on which the carriage moves ;

L an upper guide rail ;

M a plate carrying the vertical slide N, on which moves the sliding block P, to which can be attached in different positions the adapter bar Q carrying the lower yarn clamp R ;

S a pulley over which passes a cord of which one end is attached to the sliding block P and the other to a return-motion weight T at the back of the frame ;

U a pulley under which passes a string connecting the sliding block P to a peg on the metal strip V (attached to the carriage) which limits the backward motion of the carriage (and rise of the lower yarn clamp) by engaging on an adjustable stop W on the lower rail ;

X and Y two pulleys over which pass cords attached at one end to the carriage and at the other to two equal weights, not shown in the figures.

To the carriage is attached a metal slide carrying a piece of beaver board, to which may be pinned the paper on which a record is desired.

Normally the lower yarn clamp is held in its highest position by the action of the return weight T. The yarn, after fixing between the two clamps, may be extended by moving the carriage to the right. The graphs shown below were obtained by operating by hand on the end of a bar of wood nailed to the pulley X. An apparatus for producing an accurately uniform velocity of any desired magnitude is in process of construction.

The pen carrier F is pivoted on a horizontal arm, which is clamped to the cantilever spring. It is arranged so that when in use its centre of gravity is in the same horizontal plane as the axis about which it pivots (*i.e.*, so that its natural position is horizontal with the pen pointing upwards). This ensures that the pressure of the pen on the paper is independent of the precise inclination of the pen carrier.

The adapter bar may be fixed in different positions giving test lengths of yarn varying from extremely short lengths to 19 in. The longer lengths are obtained by inverting the adapter bar. In the case of the particular type of clamp shown in the figures, this involves inverting the clamp relative to the adapter bar. The maximum possible length may be increased by shortening the cord connecting the carriage to the sliding block.

It may be mentioned that this cord must have a negligible extensibility, otherwise the forward and backward journeys will not give coincident traces even with an inextensible specimen. We have used a length of flex with the outer insulation stripped. The machine has been constructed in the engineering department by Mr. J. Amos, to whom the writers are much indebted both for his skill and for many excellent suggestions with regard to mechanical details.

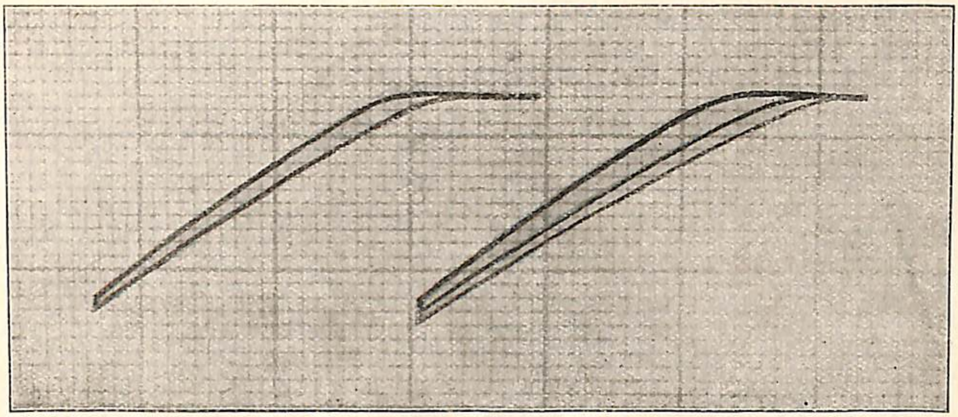

Fig. 4.

19 cm. of 2/36's worsted yarn.
3 sec. journeys.
27 sec. rests.
1 cm. sag = 103 grm.
linear magnification 1·76.

4.—SOME TYPICAL CURVES

A considerable range of different yarns has been examined by the aid of this machine. This includes single woollen and worsted yarns and folded yarns.

Figs. 4, 5, 6 and 7 are reproduced from photographs of records taken on millimetre paper. Nothing has been added to the records, not even the oblique axes.

In the case of Fig. 4, a 19 cm. length of a 2/36's worsted yarn was tested. After the yarn was fixed the carriage was moved forward a distance of 33 mm., the journey taking 3 seconds. The carriage was then held stationary for 27 seconds, and then moved back to its initial position in 3 seconds. The carriage was then held stationary for 27 seconds. The double journey with rests at both termini was then repeated three more times. Between the second and third journeys the beaver board was traversed 24 mm. to the right to avoid confusion in the record, so that in the figure

the record of the third and fourth double journeys lies to the left of that of the first and second. The lowest two lines in the right-hand portion of Fig. 4 represent respectively the first and second forward journeys. The uppermost line represents the first and second backward journeys, the two traces being so close together that they form merely a single thick line. The lower line of the left-hand portion of Fig. 4 represents the practically coincident traces of the third and fourth forward journeys, and the upper line the traces of the third and fourth backward journeys.

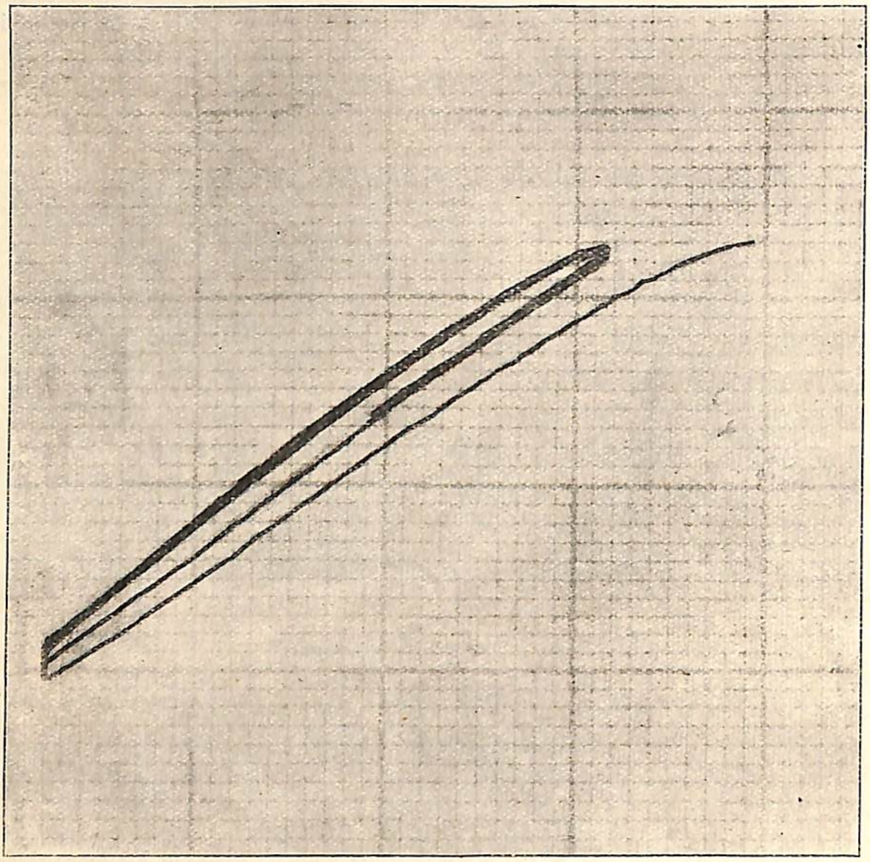

Fig. 5.

19 cm. of 2/36's worsted yarn.
4 sec. journeys.
56 sec. rests.
1 cm. sag = 103 grm.
linear magnification = 2·43.

The above method of performing the to and fro journeys results in the yarn being slack at the end of the return journey. The fact that the trace of a forward journey lies below that of the previous backward journey shows that the yarn has to some extent tightened up during the rest. This tightening can in general be seen if the yarn be watched carefully during the terminal rest.

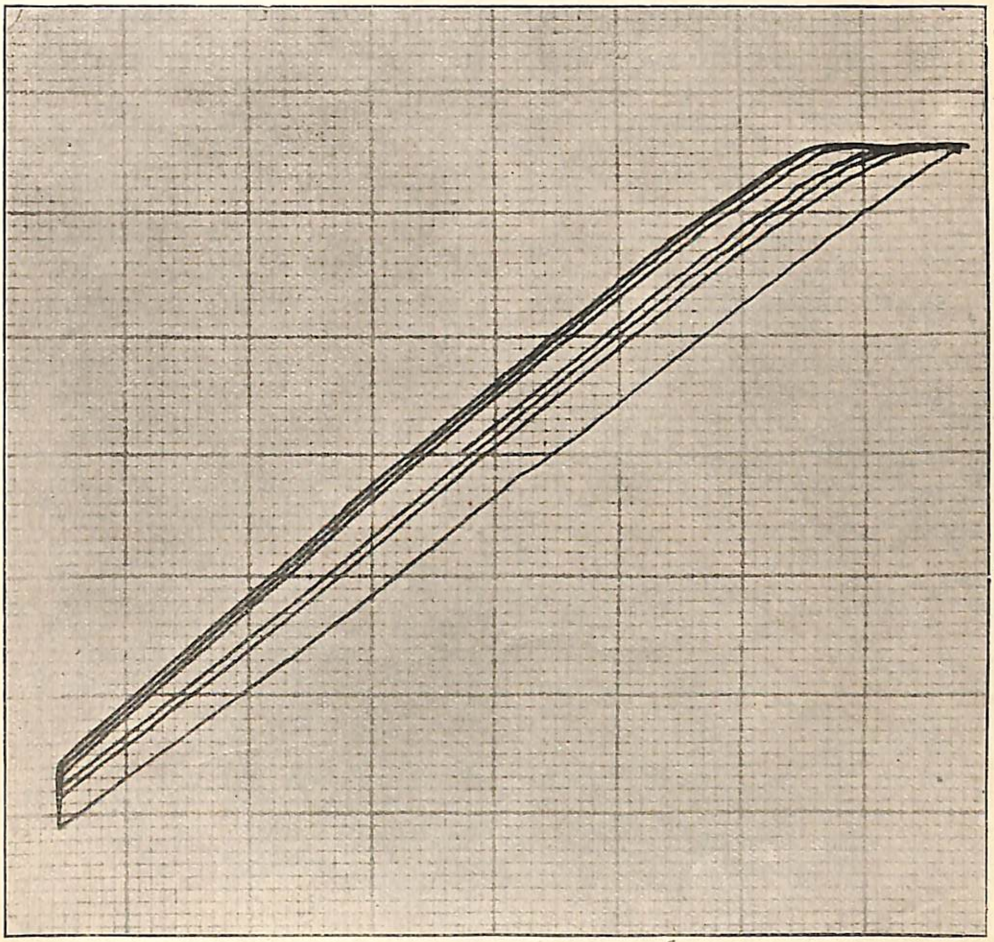

Fig. 6.

20·9 cm. of 4/40's worsted yarn.
5 sec. journeys.
15 sec. rests.
1 cm. sag = 75·2 grm.
linear magnification = 1·59.

It is not our intention to deal here at any length with the interpretation of the records, but we may point out how the time factor is of supreme importance. The oblique portions of the graphs give the stress-strain relation for rapid extensions and contractions such as occur during "shedding" in a loom. The vertical portions correspond to a slow yield under tension, such as may occur with certain threads in a loom during the formation of a long "float." The fact that the trace of a forward journey lies nearer to that of the previous forward journey than to that of the previous backward journey shows that the slow yield is by no means a mere plastic yield, but is largely a true elastic yield which takes place slowly.

The recovery of the slow elastic yield is shown rather differently in Fig. 5. There the carriage has been moved not right back to its initial position, but till the tension becomes zero. The recovery then takes place against the action of the spring, and is shown by a short vertical line. The piece of yarn tested was a fresh piece of the same yarn. It was subjected to two double journeys (4 seconds, with 56 seconds rests) and a portion of a third forward journey. A line drawn upwards so as to cut the graph a little to the left of the upper vertical portion would meet in turn the traces of (1) the first, (2) the second, and (3) the third forward journeys, (4) the first and (5) the second backward journeys.

Fig. 6 gives the trace of three complete double journeys and a portion of a fourth forward journey. The carriage was moved between fixed positions as in the case shown in Fig. 4. A different length of spring was used and a different yarn (4/40's).

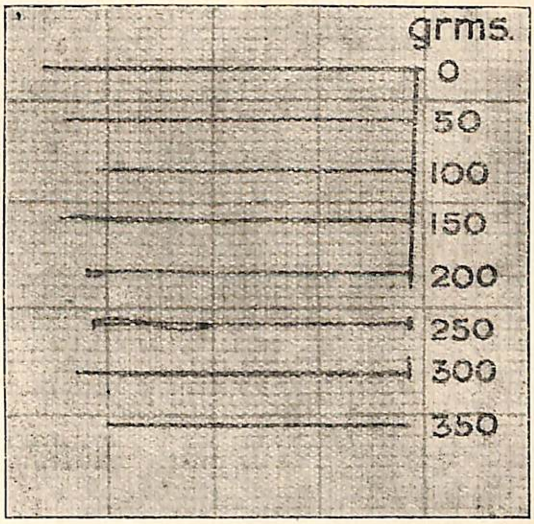

Fig. 7.
linear magnification = 1·38.

Fig. 7 illustrates the method of calibration of the spring. A piece of strong linen yarn was fixed in the upper yarn clamp and weights attached to it. Horizontal lines were drawn by lowering the pen to the paper and traversing the carriage. Each line except the lowest was drawn twice by the pen, once with increasing weights and once with decreasing weights. No effort was made to eliminate friction by tapping the board.

All the curves show the tendency for a cyclical régime to produce ultimately a steady cyclical relation between stress and strain. This point and others, relative to the elastic properties of yarns and fibres will be considered in a subsequent paper.

APPENDIX

Note on the Inertia of Cantilever Springs.

Consider a cantilever spring of length l, breadth b, and depth or thickness d. The force f for unit sag is proportional to bd^3/l^3. Now for the same value of f we may have springs whose mass varies widely. To obtain a minimum inertia effect we must have as small a mass as possible. Thus, subject to the condition

$$bd^3/l^3 = \text{constant} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{A}$$

we have to make

bdl as small as possible.

Since $bdl \div bd^3/l^3 = l^4/d^2$, this is the same as having to make

$$l^2/d \text{ as small as possible} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{B}$$

The time of vibration of a cantilever spring is proportional to l^2/d (see Rayleigh, "Theory of Sound," Vol. I., p. 220), so that this condition is equivalent to making the time of vibration as small as possible.

It is evident that for a small inertia effect the spring should be short and thick. In practice too short a spring is undesirable, so that we are limited in this direction. Considering changes in which the length remains constant, we see that for a small inertia effect the spring should be thick and narrow. There, again, we are limited by the fact that too narrow a spring tends to buckle.

In practice we cannot, therefore, diminish the inertia effect indefinitely. We can, however, make it small enough to be negligible for quite high speeds of working. The spring used at present has a period of about $\frac{1}{4}$ second even with the attachments. To get a much weaker spring suitable for fibre testing, we can in the first place diminish b. This will not affect the period. After proceeding to the practical limit in this direction it will be necessary to increase l or decrease d. So far as condition A is concerned there is nothing to choose between these alternatives. Condition B tells us, however, that it is preferable to diminish d. The attachments will of course have to be made correspondingly lighter.